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SOIL BIOGEOCHEMICAL PROPERTIES OF A KAOLINITIC ULTISOL IN RESPONSE TO FREQUENCY AND TYPE OF TILLAGE

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Abbreviations

BD, bulk density; BSR, basal soil respiration; CT, conventional chisel and disk; IC, in-row chisel; MWD, mean-weight diameter; POC, particulate organic carbon; PP, paraplow; SMBC, soil microbial biomass carbon; SOC, soil organic carbon; ST, secondary tillage; WSA, water-stable aggregation

Introduction

Soils of the Southern Piedmont USA have undergone severe erosion and degradation as a result of intensive tillage (Langdale et al., 1994). Conservation tillage can improve soil chemical, physical, and biological properties of previously cultivated soils in the southeastern USA (Beare *et al.*, 1994; Bruce *et al.*, 1995). However, little information exists on the biogeochemical effects of alternating zero tillage with secondary tillage (to control weeds) or paraplowing (to improve deep water percolation). Previous work has indicated that although sorghum [*Sorghum bicolor* (L.) Moench] yield was not affected by paraplowing frequency, a decrease in penetration resistance and an increase in water infiltration could be achieved with frequent paraplowing (Clark *et al.*, 1993). Our objective was to quantify the effects of (*i*) type of tillage that alternated with zero tillage and (*ii*) timing of the alternative tillage component on SOC, POC, SMBC, BSR, and WSA to a depth of 0.15 m.

Methods

A field experiment was initiated in the autumn of 1991 on a Cecil sandy loam (clayey, kaolinitic, thermic Typic Kanhapludult) near Watkinsville, GA. Mean annual temperature is 16.5 °C, mean annual precipitation is 1250 mm, and mean annual evaporation is 1560 mm, although typically with moisture excess from November through March. Crimson clover (*Trifolium incarnatum* L.) was grown in the winter and millet (*Panicum miliaceum* L.) was grown in the summer during the first two years. During the second two years, cotton (*Gossypium hirsutum* L.) with a rye (*Secale cereale* L.) cover crop was grown. All summer crops were zero-till planted into herbicide-killed cover crops in May/June. Periodic tillage operations alternated with zero-till planting were: IC at planting to provide a loosened soil zone below the seed, PP in autumn following harvest of the summer crop to improve deep water percolation, and ST with a wide sweep during the summer growing season to control weeds. The alternative tillage operation was performed either in 1992 (4 yr since tillage), in 1992 and 1994 (2 yr since tillage), and in 1992, 1993, 1994, and 1995 (1 yr since tillage). CT each year without cover crop was included as a control.

Rye was sprayed with paraquat in May and soil was sampled during the first week of June 1996 as cotton was emerging. Five soil cores (41-mm diam), separated by 2 m parallel to rows and 0.2 m perpendicular to rows, were collected to a depth of 0.15 m following removal of surface residue. Soil was dried at 55 °C for 48 hr, passed through a

4.75-mm screen, and stones removed. Soil BD was determined from the weight of soil prior to screening and the volume of the coring device.

Carbon mineralizaton was determined by placing two 30 or 60-g subsamples packed to 1.2 to 1.33 $Mg \cdot m^{-3}$ in 60-mL glass jars, wetting to 50% water-filled pore space, and placing them in a 1-L canning jar along with 10 mL of 1 *M* NaOH to trap CO_2 and a vial of water to maintain humidity. Samples were incubated at 25±1 °C for 24 d. Alkali traps were replaced at 3 and 10 d of incubation and CO_2-C determined by titration to a phenolphthalein endpoint. BSR was calculated as the linear rate of C mineralization between 10 and 24 d. At 10 d, a subsample was removed from the incubation jar, fumigated with $CHCl_3$ under vacuum, vapors removed at 24 hr, placed into a separate canning jar along with vials of alkali and water, and incubated at 25 °C for 10 d. SMBC was calculated as the quantity of CO_2-C evolved following fumigation divided by an efficiency factor of 0.41 (Voroney and Paul, 1984).

POC was collected from a 30 to 60-g sample shaken with 100 mL of 1 *M* $Na_4P_2O_7$ for 1 hr on a reciprocating shaker, allowed to settle in dispersing solution for 16 hr, shaken again for 1 hr, diluted to 1 L with distilled water, allowed to settle for 5 hr, and then passed through a 0.053-mm screen. Sand and organics not passing the screen were dried at 55 °C for 72 hr, ground in a ball mill for 5 min, and analyzed for total C using dry combustion.

WSA was determined using a wet-sieving procedure. A 60 to 80-g sample was placed on a nest of sieves (175-mm diam) with openings of 1 and 0.25 mm, immersed in water, and oscillated for 10 min (20-mm stroke length, 31 $cycles \cdot min^{-1}$). Floating organic material retained within the walls of the top screen was removed by suction, collected on a screen, and placed in a drying bottle. After removing the two sieves and placing soil in drying bottles, water containing soil passing the 0.25-mm screen was poured over a 0.053-mm screen and the soil retained placed in a drying bottle. The <0.053-mm fraction was calculated as the difference between initial soil weight and summation of the 1-4.75, 0.25-1, and 0.053-0.25 mm fractions. All fractions were oven-dried at 55 °C for ≥24 hr following visual dryness. MWD of soil was calculated by summing the products of WSA fraction and mean diameter of WSA class, excluding the floating material.

A subsample of soil was ground in a ball mill for 5 min and analyzed for total SOC concentration using dry combustion. Soil properties were analyzed for variance due to replication (2 df) and tillage type x frequency combinations (9 df) using the general linear model procedure of the SAS Institute, Inc. (1995). Orthogonal contrast statements were used to separate individual components of the tillage type x frequency combinations. Effects were considered significant at $P \le 0.1$.

Results and discussion

Soil BD was greater in all alternative tillage systems compared with CT (Fig. 1). When averaged across alternative tillage frequencies, BD was greater in PP and ST than in IC. Reconsolidation of soil following any alternative tillage event appeared to be near completion within one year.

MWD of WSA was greater in all alternative tillage systems when averaged across frequencies compared with CT (Fig. 1). Complementary to the effect observed in BD, MWD was greater in IC than in PP and ST. Greater macroaggregation with less soil disturbance tended to occur in all alternative tillage systems, but was not significant.

SOC was not affected by tillage type or frequency (Fig. 2). No change in SOC due to reduction in tillage on this same soil was also reported by Langdale et al. (1990), and may be due to a redistribution of SOC within the soil profile, such that only the surface 10 to 20 mm may accumulate SOC with tillage reduction (Bruce et al., 1995).

POC was greater in all alternative tillage systems when averaged across tillage frequencies compared with CT (Fig. 2). POC was greater in IC than in PP and ST when averaged across tillage frequencies.

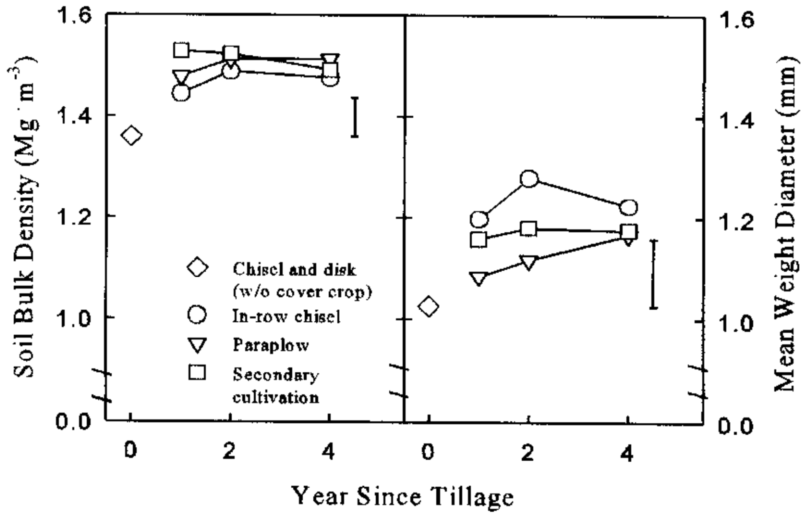

Figure 1. Soil bulk density and mean weight diameter as affected by tillage type and frequency when alternated with zero tillage. Error bar is LSD at $P \leq 0.05$.

SMBC was greater in all alternative tillage systems when averaged across tillage frequencies compared with CT, similar to the effects observed for MWD and POC (Fig. 3). No other tillage type or frequency effect on SMBC was observed.

BSR was greater in all alternative tillage systems when averaged across tillage frequencies compared with CT (Fig. 3). BSR increased with time since PP and ST, but not with time since IC.

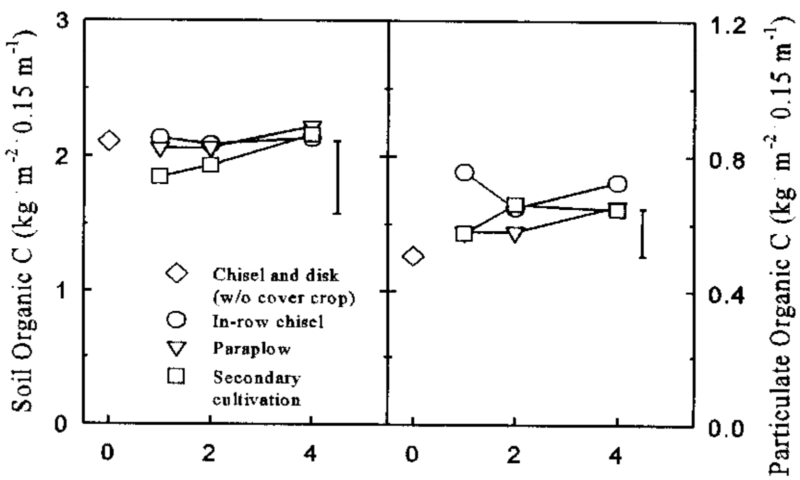

Figure 2. Soil organic C and particulate organic C as affected by tillage type and frequency when alternated with zero tillage. Error bar is LSD at $P \leq 0.05$.

Sensitivity of BSR to the change in tillage management strategies was much greater than that of other soil properties. Alternative tillage types and frequencies compared with CT averaged 46% greater with BSR, 28% greater with POC, 19% greater with SMBC, and 2% less with SOC. Similarly, BSR was found to be more sensitive to a change in tillage management in a cold, semiarid climate where little change in SOC could be detected (Franzluebbers and Arshad, 1996).

Cotton yield during was inconsistently affected by any of the types and frequencies of alternative tillage systems (data not shown). Cotton seed yield under CT averaged 0.42, 0.80, and 1.54 $Mg \cdot ha^{-1}$ in 1994, 1995, and 1996, respectively. However, cotton seed yields in alternative tillage systems in 1994, 1995, and 1996 were 0.76 ± 0.09, 0.89 ± 0.11, and 1.64 ± 0.11 $Mg \cdot ha^{-1}$, respectively.

Conclusions

We conclude that improvement in soil properties could be achieved using any of the tillage systems alternated with zero tillage. Compared with 4 yrs since the last alternative tillage event, more frequent alternative tillage operations did not improve soil properties and were a detriment to aggregation and accumulation of active fractions of soil organic matter. However, the detrimental effects of alternative tillage were not as severe as continuation of CT. Judicious and infrequent use of IC to improve seed establishment, PP to improve deep water percolation, and ST to control summer-season weeds, which all minimize surface residue incorporation, in combination with zero tillage should be considered viable alternatives to CT, which leaves little protective cover on these highly-erodible soils.

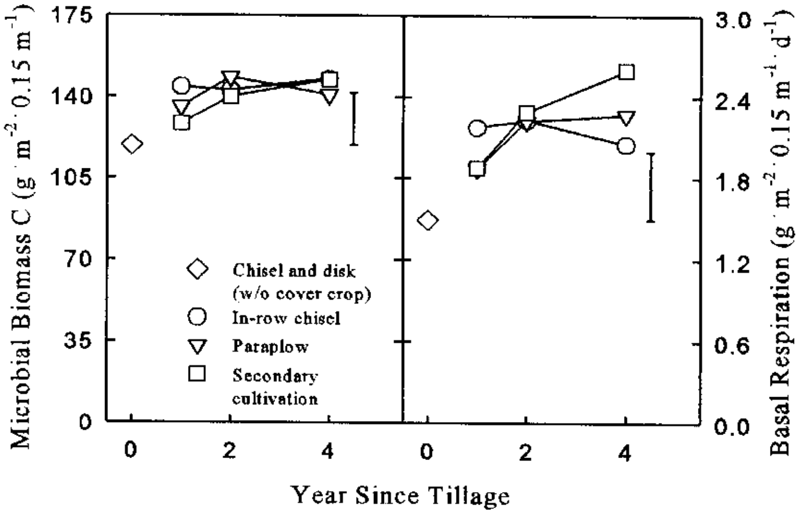

Figure 3. Soil microbial biomass C and basal soil respiration as affected by tillage type and frequency when alternated with zero tillage. Error bar is LSD at $P \leq 0.05$.

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